A STUDY OF FELDSPAR TWINNING IN A DIFFERENTIATED SILL

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ABSTRACT

The observation has frequently been recorded that certain twinning laws (such as pericline) are more commonly encountered in basic rocks, while other laws are especially characteristic of acid rocks. As a follow-up on this observation and in a search for the causes that control twinning, a suite of thin sections taken from the bottom to the top of a differentiated sill was studied statistically to determine whether there are any variations in the nature of the twinning with change in composition of the rock. Over fourteen hundred twins were examined. They showed a statistical increase in the *number* of twins with increase in basicity, or anorthite content, of the sill. They indicated that there is no change in, or control of, the *type* of twinning law with the composition of the rock as it appears after crystallization. Another factor still unknown, and not composition must be responsible for the variation in twinning in different types of rocks.

INTRODUCTION

The determination of feldspar twinning laws, though regarded as an interesting study, has not yielded results of a practical nature, and therefore has not received sufficient attention by the American petrographers.[1] The more common twinning laws are well known by name, but are usually assumed rather than determined. The rarer laws are far too little known even by name. We have virtually no understanding of the relationships between twinning and rock type. The underlying factors which decide which twinning law shall prevail, are quite unknown. Feldspar twinning, at present, is little more than a useful criterion for the ready recognition of the mineral. It is incredible that a phenomenon so common as feldspar twinning can be so devoid of significance.

On the tentative assumption that the twinning laws present in a given rock might be a characteristic of that rock and serve as an earmark for purposes of correlation, a study was made of the twinning of

[1] As early as 1876 Rath (36) described twins of the Manebach and pericline laws, and his work was soon followed by similar descriptions by Mallard (26) in 1876, Michel-Lévy (31) in 1879, Glinka (16) in 1889, Viola (47) in 1900, and Melczar (30) in 1905. These early determinations were made by measuring angles on the goniometer. Real advance in the study came with Fedorov's invention of the universal stage method, described in 1901 (14). Nikitin (32), a pupil and collaborator of Fedorov, was one of the first to use this method. Duparc (11) introduced Fedorov's methods to the Laboratory of Mineralogy of the University of Geneva in 1912, having himself learned them directly from Fedorov and Nikitin. With the improvement in method the study of twinning proceeded rapidly, led by Nikitin, Duparc, and Reinhard, until now the study of twinning laws is an accepted part of the complete study of structure containing feldspars.

some of the granites of the Front Range.[2] This yielded no definite results, possibly because the thin sections represented widely scattered specimens from large areas. It was decided in any case to attempt to learn first something about the underlying reason for the occurrence of one type of twin rather than another. A smaller formation was therefore studied in greater detail—one showing a variable composition.

Several petrographers[3] have noted an apparent connection between the composition of a rock and the twins present. Albite and Carlsbad twinning, for example, though common in all plagioclase, predominate overwhelmingly in rocks containing sodic feldspars. Pericline twinning is a common occurrence in rocks containing calcic feldspars. The conclusion has been drawn that a composition of the crystallized rock in some way is a factor at least, in deciding the twinning laws which may develop. If this is true, then twinning is robbed of any apparently useful meaning. If not true, then the underlying controlling factors invite investigation. The present study outlines the relationship between twinning and composition as revealed in an occurrence which is believed to be favorable for the purpose.

A diabase sill outcropping in Concession 1, lot 12, Bridgland Township, District of Algoma, Ontario, was chosen for study. The sill shows differentiation to a considerable degree, and therefore affords an opportunity to compare the feldspar twins present with more than one compositional rock type, under conditions such that the variable factors within the range of rock types are at a minimum.

A detailed description of the sill and a chemical study of its differentiates has already been published.[4] A fresh suite of specimens was collected for this study, with the present purpose in mind. Over the measured thickness of 1100 feet specimens were taken. Thin sections were cut from these.

Some pertinent details for this discussion may profitably be repeated

[2] Specimens were obtained through the courtesy of Margaret Fuller Boos, *Bull. Geol. Soc. Am.*, vol. **45**, pp. 303–332, 1934.

[3] Gysin (17) (18) (19), Coulson (5), and Lodochnikov (25), have attempted to correlate twinning and composition. More frequently, however, accounts noting both phenomena, such as those of Herrmann (20), Vendl (46), and Kolaczdowska (23), lack this effort to find a specific significance for twinning. Another group have placed entire emphasis on twinning, but merely list the number of twins according to the various laws. Examples may be found in the works of Azzini (1), Baier (2), Carrasco (4), Dolar-Mantuani (7), Drugman (8), Duparc (10), Lewis (24), Palinc (34), Sabot (39), Schlossmacher (40), Solinac (42), and Wieseneder (50). Finally, there are those who note twinning incidentally to their other studies as: Diehl (6), Duparc (9), Ghika-Budesti (15), Jahn (21), Johs (22), Maroscheck (29), Riba (37), Spencer (43), and Wang (49).

[4] Emmons, R. C., *Am. Jour. Sci.*, vol. **13**, p. 73, 1927.

here. A slightly aschistic zone is present at the lower contact. A shear zone crosses at approximately 262 feet above the base. The main body of the sill is typically diabasic, medium grained, and has a poikilophitic texture. A coarse pegmatite enters near the top of the sill, but was avoided in sampling. Red feldspars become evident near the upper portion, giving the rock a slightly pinkish hue. Pyroxenes are the dominant ferromagnesian minerals, but are altered to amphibole in the shear zone and the upper portion of the sill. Biotite and epidote tend to be concentrated in the upper phases, however veins of epidote are also present in the aschistic zone. Quartz, with a vermicular texture, likewise is found in the aschistic zone and not again until the upper portion is reached where graphic texture is prominent. The feldspars throughout the lower and main portion of the sill are generally free of alteration, and many exhibit strain and zoning. Near the top and in the shear zone they are extremely sericitized and chloritized. In the lower portion of the sill there are more than twice as many feldspars as other mineral crystals, while in the upper portion there are less than half as many feldspars. In composition they range from bytownite (An_{75}) to oligoclase (An_{32}).

Method of Study

The feldspar twinning laws and compositions were determined in thin sections with the aid of the universal stage. Most of the determinations were done by Rittmann's Zone Method[5] (38) which is satisfactory in the majority of cases. It fails when the composition is over 75 per cent An. It fails also in making a reliable distinction between Manebach Ala A twins and Manebach-akline twins. Likewise, in the acid feldspars of about 28 per cent An content there is difficulty in distinguishing between albite and albite Ala twins, as has been pointed out by Manolescu (28).

When it was impossible to use Rittmann's method and also as a check on that method, the procedure of Fedorov-Nikitin[6] (11) was followed. This involves more time but gives more accurate results; therefore, several twins in each thin section were determined by this method in order to check the results found by that of Rittmann. The only limitation here is in the width of the twin lamellae, the very narrow ones being impossible to orient if they disappear from view on inclination of the inner stage. Since a considerable part of the work employed the Fedorov-

[5] This is a method whereby the composition plane of a twinned feldspar is oriented vertical and parallel to the N-S axis, and critical extinction angles are read from a known recognizable direction in the composition plane.

[6] This is the original method of Fedorov consisting of plotting critical optical data for two or more lamellae on a stereographic projection. The relationship between lamellae thus brought out discloses the twinning axis. The attitude of the twinning axis relative to any crystallographic datum plane discloses the twinning law and composition.

Nikitin method, the modified universal stage was used, which greatly simplifies the procedure and lessens the time required for its manipulation. The modified stage offers no advantages for Rittmann's method.

Coulson (5) has demonstrated by means of projections on (010) that there is a possibility of confusing albite Ala B twins of 33 per cent An with Albite-Carlsbad twins of 0.5 per cent An; however, this limitation hardly enters into the present study.

By means of the above procedures an attempt was made to determine the twin laws of every twinned feldspar in each thin section, all

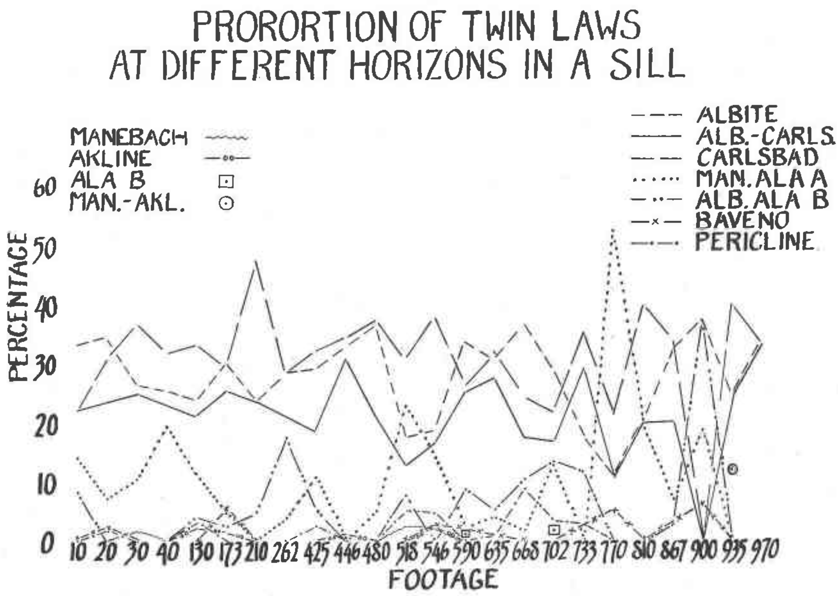

Fig. 1

thin sections being approximately the same size. The results are given in table 2 and figure 1.

Having determined the twin laws, statistical methods were then used in order to express the relationships in more exact terms than is otherwise possible. These appear in tables 3 and 4, and figures 3 and 4.

The composition was determined on an average of ten of the twinned feldspars studied in each thin section. Compositions were found by means of extinction angles on Rittmann's figures, and were checked on the twin-axis curves of Fedorov's projections. Manolescu (28) has shown that the composition plane is apt to be made up of vicinal faces and therefore does not afford a reliable An content determination. For this reason the twin-axis curves of Fedorov's diagrams as corrected by Nikitin's later data (13) (33) were used. Projections of [001] give still more accurate results but are not always available and are more difficult to use.

The composition selected as representative of the thin section was the average of all found by the above two methods, a range of about 10 per cent having been present in each slide.

A further check on composition was made by the totally different Tsuboi (45) method. This involves chipping off a feldspar cleavage flake, immersing it in a liquid of approximately the same index, and finding the refractive index of the fast ray for this orientation.

The results from the above two methods are plotted on figure 2, together with a general average of the two groups of data.

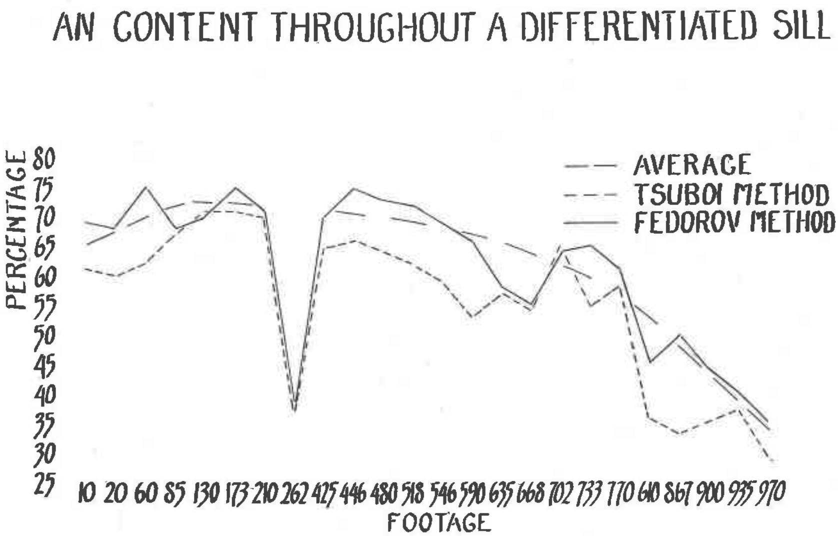

FIG. 2

DISCUSSION

The following conclusions represent earlier attempts to find a reason for specific twin occurrence: pericline twinning is most closely associated with plutonic rocks (18) (35), akline twinning is confined mainly to effusive rocks (18); albite twinning is predominant in albite, and Carlsbad twinning in oligoclase feldspars (25). However, when the findings of several writers are tabulated, as in table 1, showing the least and greatest anorthite content at which a given twinning law is found, it will be seen that each law is found throughout a fairly wide range, and not confined to any given composition.

The following discussion, though not solving the problem, does eliminate from this occurrence certain factors which formerly were thought to control twinning. Table 2 and figure 1 indicate that although each twin law varies in frequency from bottom to top of the sill, its average would not digress markedly from a straight line. No twin is found in only one section of the sill; the acidic upper portion contains about the same types of twins as the more basic lower portion. An exception may be noted in the last two sections which lack the more rare twin types, and the latter of these two sections also is the only one containing Manebach-akline twinning. However, little weight can be given to these exceptions because: alteration of the feldspars is so heavy in this portion of the sill that the chance for error in orientation by any method is very great; the total number of twins is not large; those which could be oriented were so few in number that all classes could not be filled; and there is difficulty in distinguishing between Manebach Ala A and Manebach-akline by Rittmann's method, which had to be used here on account of the narrowness of the lamellae.

TABLE 1

Twin Law	Upper and Lower Limit An Content
Carlsbad	0–73
Albite-Carlsbad	0–73
Albite	0–73
Ala	1–75
Pericline	22–90
Manebach Ala	50–63
Manebach-akline	20–64
Baveno	23–40
Albite Ala B	35–80

References: (46) (50) (20) (23) (17) (19) (5) (11)

The common belief that certain twins occur more frequently in acid rocks than in basic, and vice versa, is brought out by the works of Coulson (5), Gysin (17) (19), Phillips (35), and Lodochinkov (25). This differentiated sill, having a slightly aschistic phase in the lowest portion which verges into a normal diabase with a gradually more acidic upper portion, gives a great enough range in composition to show if there is a tendency for any twinning law to be specifically associated with a given composition. Such a tendency is, however, not apparent from these data. Any twin given in table 2 may be traced from bottom to top of the sill even though there is variation in frequency from section to section. (An exception is the Ala B and Manebach twins which occur so rarely that no conclusion may be drawn.) The shear zone represents a sudden, very acidic phase in the sill as is shown in figure 2. This zone emphasizes that no types of twinning are to be more closely correlated here with composition than other types.

TABLE 2. NUMBER OF TWINS

Foot-age	An %	Alb.-Carl.	Carl.	Alb.	Man. Ala A	Alb. Ala B	Bab.	Akl.	Ala B	Per.	Man.-akl.	Man.	All Twins
10′	69	8	8	12	5	3							36
20′	68	26	34	38	8		2			2			110
60′	75	17	25	18	7							1	68
85′	68	11	15	12	9								47
130′	70	28	42	30	14	5		3		4			126
173′	75	32	37	38	6	3	7	2					125
210′	71	5	10	5		1							21
262′	38	6	8	8	1	5							28
420′	70	7	12	11	4	2				1			37
446′	75	58	64	61				2					185
480′	73	17	30	29	4								80
518′	72	5	12	7	9	3				2		1	39
546′	69	7	16	8	6		1	1		2		1	42
590′	66	23	24	31	2	8	2		1				91
635′	58	25	31	30	4	5	1			1			97
668′	55	10	14	21	1	6				5			57
702′	64	10	13	17	8	8			1	2			59
733′	65	10	12	6		4	1			1			34
770′	61	2	4	2	10		1						19
810′	45	1	2	1	1								5
867′	50	12	20	19	4	2	2						59
900′	44	0	0	6	3	6	1						16
935′	40	6	10	6							3		25
970′	35	1	1	1									3
													1406

In order to secure sufficiently large numbers in each class, twins, from adjacent specimens, of similar composition from different horizons were grouped together, care being taken not to break up petrographic relationships. The 10–20 foot group-level was then correlated with each succeeding group-level as shown in table 3. The coefficients of correlation (r) between the lowest (10′–20′) level and each of the other group-levels are very high. This means that this level (10′–20′) is very similar to each other level. Because the coefficients of correlation are not directly comparable they are given in squared form in figure 3. These expressions,

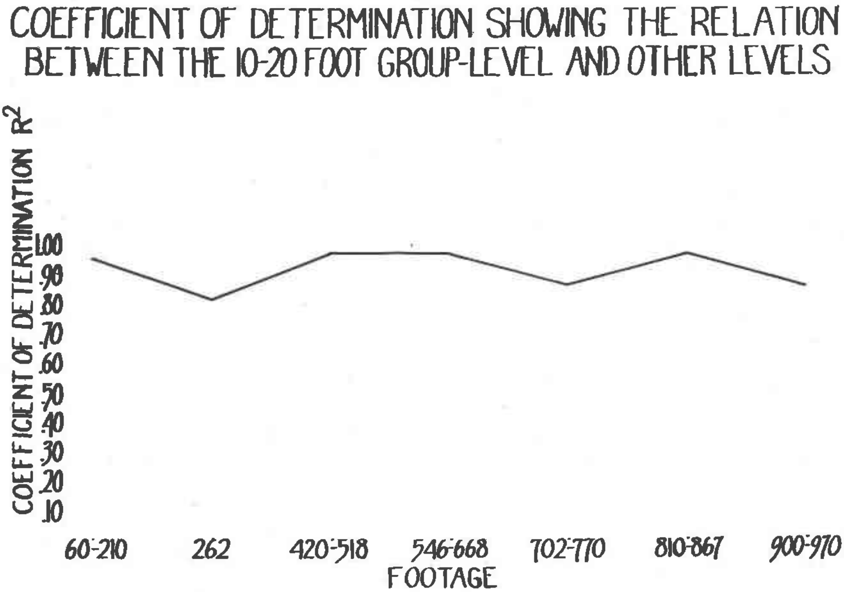

FIG. 3

(r^2), termed coefficients of determination, are proportional to each other and therefore can be treated as percentages. In this analysis they are used in a manner similar to that reported by Dryden[7] for heavy minerals; that is, to measure the similarity of the proportions of different twinning laws in the two group-levels correlated. By dividing the sill into these groups representing various compositions, it is shown that the type of twinning is much the same throughout the sill regardless of change in composition.

TABLE 3. CORRELATION BETWEEN PROPORTION OF TWIN LAWS AT GROUP-LEVEL 10′–20′ AND OTHER GROUP-LEVELS

Group-Level	Number of Twins	Correlation Coeff. with 10′–20′ Level	Coeff. of Determination
60′–210′	337	0.976	0.953
262′	28	.903	.810
420′–518′	341	.985	.970
546′–668′	287	.986	.972
702′–770′	112	.923	.852
810′–867′	64	.984	.968
900′–970′	44	.922	.850

[7] Dryden, L., A statistical method for the comparison of heavy minerals: *Am. Jour Sci.*, vol. **29**, no. 173, p. 393, 1935.

In order to study the variations of each twinning law more specifically, correlations between the anorthite content and frequency of type of twinning,[8] as well as the total number of twins, were calculated. The An content and the total number of twins show a highly significant positive correlation (table 4). Toward the more basic wall of the sill, the relative number of twinned feldspars increases. Therefore, it is important to know whether the increase in total number is the result of a marked increase in only one twinning law, or whether it is proportional for all laws. If proportional, then no twinning law shows a definite association with a specific composition; if not proportional, then some twins must occur relatively more often at a given composition. Each correlation for the

TABLE 4. CORRELATION BETWEEN TWIN LAWS AND ANORTHITE CONTENT

Type of Twin	Number of Twins	Correlation Coeff. with An Content	Probability	Coeff. of Deter.
All twins	1406	0.505	$\doteq$0.01	0.255
Alb.-Carls.	326	.472	$\doteq$0.02	.223
Carlsbad	443	.493	$\doteq$0.01	.243
Albite	416	.441	$\doteq$0.04	.194
Man. Ala A	106	.410	$\doteq$0.05	.168
Albite Ala B	61	−197	>0.05	.039
Baveno	18	.157	>0.05	.025
Akline	8	.368	>0.05	.134
Pericline	20	.099	>0.05	.009
Manebach	3			
Ala B	2			
Man.-akline	3			

more common types—Carlsbad, albite, albite-Carlsbad, and Manebach Ala A—is significant and of about the same order as the correlation between An content and total number of twins (table 4). This means that each type of twin increases with increasing An content and to about the same extent. In other words, the increase of each is proportional to the increase of the total number of twins. The rarer twins, on the other hand, show an insignificant correlation, and would probably occur more than 5 per cent of the time by chance. This may be due to the few numbers in these classes, or to the fact that these twins are scattered at random with relation to the An content and therefore at random throughout the sill. The coefficients of determination are shown graphically in figure 4.

[8] Manebach, Ala B, and Manebach-akline twins were not included because they were present in such small numbers.

The cause of twinning in feldspars is generally conceded to be differential stress (44) applied to the crystal at any time but usually in igneous rocks at or near the time of crystallization. Some metamorphic rocks show feldspar twinning which appears to be a modification of original twinning. Further work on metamorphic suites suitable for this purpose should yield interesting results. Mutual interference of growing crystals is probably a most common cause of the stresses required. It appears to be true, however, that although differential stress is the cause of twinning, there are other factors which are extremely important in deciding what twins shall respond to the stresses present. This other con-

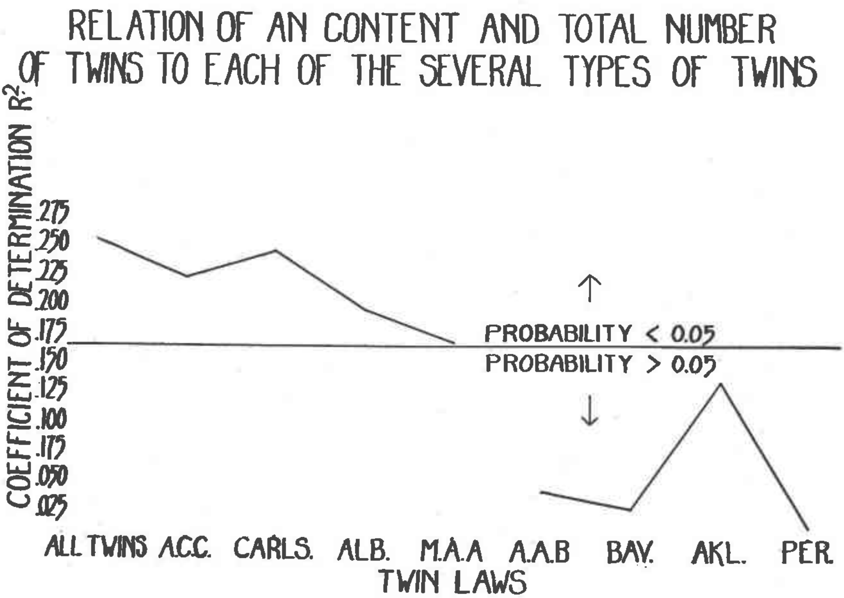

FIG. 4

trol is the object of our present interest. It has been attributed to composition of the rock in some unknown way as indicated above. The facts brought out in this study militate against this view unless by composition is meant the composition of the magma rather than the rock as we know it.

It is hoped by a process of further elimination to learn more about the nature of these controlling factors. There is need for further confirmatory information of the type presented here. Needed, also, is more information on the nature of the differences in twins between igneous and metamorphic rocks. And it is especially desirable to learn the extent to which twinning may vary from point to point in one rock body.

Parenthetically attention may be called to two interesting sidelights encountered during the present study. The first is brought out in figure 2 which shows the apparent discrepancy in measurements of composition by Fedorov's and Tsuboi's methods. Mention has been made that an apparent range of 10 per cent in composition is evident from Fedorov's method. So persistent is information of this sort that it seems necessary to assume either that contiguous feldspars vary in composition or optical methods have limitations which are not generally admitted.

TABLE 5. COMPARISON OF TWINS IN DYNAMITED AND UNDYNAMITED ROCK

	Micro-cline	Albite	Carl.	Alb.-Carl.	Albite Ala B	Man.-akline	Total
(F_1i) No. *Dyn.* %	26 37.68	19 27.54	10 14.49	7 10.14	4 5.80	3 4.38	69(T_1)
(F_2i) No. *Undyn.* %	44 56.41	20 25.64	9 11.54	4 5.13	1 1.28	0 0.00	78(T_2)
Total No. (Ti)	70	39	19	11	5	3	147
*$1/Ti(F_2i \times T_1 - F_1i \times T_2)^2$=	14515	267	1331	6627	11810	18252	

$\Sigma_1^n 1/Ti(F_2i \times T_1 - F_1i \times T_2)^2 = 52802$

$X^2 = \Sigma_1^n 1/Ti(F_2i \times T_1 - F_1i \times T_2)^2 = 52802/5382 = 9.81$

therefore $P \doteq 0.10$

* Formula derived from Fisher's work. Fisher, R. A., Statistical Methods for Research Workers. 3d Edition. Oliver and Boyd, *Edinburgh* and *London*. Pp. 75–98, 1930.

The second sidelight developed from a brief study made on slides which were generously loaned by Professor E. Blackwelder. One slide represents granite which was dynamited in the Yosemite Tunnel, the other, undisturbed granite "from a small quarry in the same formation as that pierced by the Yosemite Tunnel and less than half a mile due north from it. I think very little blasting has been done in the quarry as the rock is well jointed."[9] It was thought that a comparison of these rocks would reveal any possible influence on twinning which such pressures as dynamiting could produce. A statistical study of the twins showed (table 5) that the proportions of the different twins did not differ significantly in the two slides. The effect on twinning is, therefore, not measurable though the rock itself was badly shattered. (The distance between the two specimens is considerable, but satisfactory for negative results.)

[9] Quotation from letter.

The writer is greatly indebted to Professor R. C. Emmons who suggested this study and under whose direction the work was done.

Summary

The intensive study of feldspar twinning by earlier workers has revealed much about the nature of twinning and its occurrence, but has led to virtually no understanding of the ultimate factors which decide which twinning law shall develop. Nor has any practical use been made of this twinning.

A few authors have suggested that certain twinning laws may be restricted to a specific anorthite content of feldspar. Several have called attention to the common differences in frequency of twin-law occurrence in granites and gabbros.

It has been tentatively believed by many that the composition of the feldspar or of the rock, was a controlling factor in deciding which twin-law should occur.

The present study shows that *in a differentiated sill ranging in feldspar composition from An_{75}–An_{32} the relative frequency of occurrence of one twinning law with respect to another is essentially constant.* This does not hold for the rarely occurring laws. So few of these were found, however, that the lack of agreement for the rare laws is only a tentative conclusion and applies only to this study.

The apparent difference in twinning in granite and gabbro remains unexplained. Further studies will be directed toward its solution.

Literature Cited

1. Azzini, F., Adularia e albite di Val Devero (Ossola): *Min. Abst.*, vol. **5**, no. 8, p. 366, 1933. Adularia crystals are twinned on Baveno and Manebach laws.
2. Baier, E., Lamellenbau und Entmischungsstruktur der Feldspäte: *Zeit. Krist.*, vol. **73**, pp. 465–560, 1930.
Rittmann's methods are described. The twin laws of 170 rocks are given.
3. Boos, M. F. and Boos, C. M., Granites of the Front Range—The Longs Peak—St. Vrain Batholith: *Bull. Geol. Soc. Am.*, vol. **45**, pp. 303–332, 1934.
4. Carrasco, E., Contribution à l'étude des macles des feldspaths au moyen de la méthode de Fedoroff: *Bull. Soc. Vand. Sci. Nat.*, vol. **52**, pp. 483–564, 1920. Thirty-seven feldspar crystals are tabulated.
5. Coulson, A. L., The albite-Ala B twinning of plagioclase feldspars in certain acidic rocks from the Sirohi State, Rajputana: *Rec. Geol. Surv. India*, vol. **65**, pp. 173–184, 1931. Twin laws and compositions are noted from some dillenites and porphyries. Favorable compositions for certain twin-laws are noted.
6. Diehl, O., Mikroskopische Beobachtungen und kristalloptische Messungen an Mineralien in Basaltgesteinen der Umgebung Alsfelds in Oberhessen: *Neues Jahr. f. Min.* **1, A,** p. 78, 1926. The feldspar twins found in the basalt are listed.
7. Dolar-Mantuani, L., Zur Charakteristik der Feldspate des Syenites vom Gröba-Typus: *Min. Petr. Mitt.* (Tscherinak), vol. **41**, pp. 272–307, 1931. Anorthoclase phenocrysts

are studied by Fedorov's method, and the observation made that Carlsbad and Manebach twins occur frequently.

8. Drugman, J., Sur deux macles rares des Orthoses de Zarzalejo: *Rev. de Géol.*, vol. **11**, p. 210, 1930. Carlsbad and Baveno twins are described.
9. Duparc, L., Sur un trachyte à anorthose de Gambeila (Abyssinie): *Rev. de Géol.*, vol. **11**, p. 212, 1930. Carlsbad twinning is present in the feldspars.
10. Duparc, L. and Galopin, R., Sur les relations entre les phénocristaux et les microlites des plagioclases des Basaltes Äbyssins: *Rev. de Géol.*, vol. **12**, p. 574, 1932. Albite twinning is present in the phenocrysts. Carlsbad and albite-Carlsbad twins are present in the microlites.
11. Duparc, L. and Reinhard, M., Les méthodes de Féderof et leur application à la détermination des plagioclases: *Bull. Swisse de Min. et Petr.*, Tome **111**. Fedorov's methods are described.
12. Duparc, L. and Sabot, R., Les méthodes de Féderov: *Geol. Centr.*, vol. **19**, p. 355, 1913. Fedorov's methods are described.
13. Emmons, R. C., Plagioclase determination by the Modified Universal Stage: *Am. Mineral.*, vol. **19**, no. 6, pp. 237–259, 1934. Plagioclase determinations by Fedorov's methods are given.
14. Fedoroff, E., Neue Varrichtungen zum Polarisationsmikroskope: *Geol. Centr.*, vol. **2**, no. 1465, 1901. A description of his universal stage is given.
15. Ghika-Budesti, St., Les plagioclases des Banatites étudiés par la méthode Fédoroff: *Rev. de Géol.*, vol. **12**, p. 125, 1931. Mention is made that twin-laws and composition vary.
16. Glinka, S., *Russ. Bergjournal*, **1889**. Cited from Lewis (24).
17. Gysin, M., Note sur l'étude de quelques caractères des plagioclases: *Neues Jahr. f. Min.*, vol. **2**, p. 199, 1926. Feldspar twins and their An content are listed.
18. Gysin, M., Sur la présence de la macle de l'acline—A dans les plagioclases: *Neues Jahr. f. Min.*, vol. **2**, **A**, p. 198, 1926. Pericline is more common in plutonic rock and akline more common in effusive rock.
19. Gysin, M., Sur certaines roches de la Pawdinskaya-datcha (Oural): *Min. Abst.*, vol. **3**, no. 11, p. 516, 1928. Pericline twins are abundant in troctolites, and the composition remains almost invariably about 89 per cent An. Albite twins vary in composition in the same sense as the basicity of the rock.
20. Herrmann, E., Über Zwillingsverwachsungen gesteinbildender Plagioklase: *Zeit. Krist.*, vol. **59**, pp. 513–547, 1924. The twin-laws and An content of 86 feldspars are given. Twins ⊥[010] (100) and ⊥(100) are recorded here and have not been found elsewhere.
21. Jahn, A., Beiträge sur Mineralogie des Vogtlandes: *Min. Abst.*, vol. **5**, no. 11, p. 487, 1933. Descriptions are given of five feldspars twinned on Manebach, Carlsbad, and Baveno laws.
22. Johs, M., Der Granitporphyr von Thal Heiligenstein im Thüringer Wald: *Min. u. Petr. Mitt.*, vol. **43–44**, pp. 283–313, 1933. The twin-laws present in the plagioclases are noted.
23. Kolaczkowska, M., Études microscopiques de plagioclases provenant des andésites de Wżar tenant compte de quelques nouvelles méthodes d'examen: *Zeit. Krist.*, vol. **72**, pp. 58–106, 1929. An content and twin-laws are given.
24. Lewis, W. J., On crystals of albite from Alp Rischuna, and pericline twins from La Fibbia, Switzerland: *Min. Mag.*, vol. **17**, no. 81, pp. 178–192, 1915. Albite and pericline twins, measured on a goniometer, are described in detail.
25. Lodochnikov, V. N., Recherches microscopiques des feldspats et les conclusions tirées pour les roches du district de Zaïssane (gouv. Sémipalatinsk): *Min. Abst.*, vol. **3**, no. 4,

p. 195, 1926. The twins in 287 igneous rocks are listed, and a discussion is given of the cause of twinning and the effect of pressure.

26. Mallard, *Ann. Mines*, vol. **10,** p. 10. 1876. Cited from Taylor (44).
27. Malmquist, D., Über den Amphodelith und ähnliche, umgewandelte Anorthite: *Bull. Geol. Inst. Upsala*, vol. **22,** pp. 161–182, 1927. A number of feldspar twins are listed.
28. Manolescu, G., Über die Lage der morphologischen Bezugrichtungen bei Plagioklasen und ihre Verwendbarkeit zur Bestimmung des Anorthitgehaltes: *Sweiz. Min. Petr. Mitt.*, vol. **14,** p. 453, 1934. Twinning is discussed with reference to Fedorov's method.
29. Maroscheck, E. F., Beiträge zur Kenntnis des Granites von Mauthausen in Oberösterreich: *Min. u. Petr. Mitt.*, vols. **43–44,** pp. 375–403, 1933. Albite and albite-Carlsbad twins are found here.
30. Melczar, G., *Zeit. Krist.*, vol. **XL,** p. 571, 1905. Cited from Lewis (24).
31. Michel-Lévy, *Bull. Soc. Min.*, vol. **2,** p. 135, 1879. Cited from Taylor (44).
32. Nikitin, W. W., Halbsphäroid sur graphischen Lösung bei Anwendung der Universalmethode: *Zeit. Krist.*, vol. **47,** p. 379–381, 1910. The principals of the universal stage method are given.
33. Nikitin, W. W., Korrekturen und Vervollständigungen der Diagramme zur Bestimmung der Feldspate nach Fedorows Methode: *Min. Abst.*, vol. **5,** no. 8, p. 364, 1933. Previous curves made for Fedorov's method are revised and improved.
34. Palinc, G., Untersuchungen der Plagioklase einiger tertiärer Ergussgesteine Siebenburgens (Rumänien), mittels der Universaldrehtischmethode: *Neues Jahr. f. Min. u. Geol.*, vol. **1,** p. 392, 1934. The frequency of albite-pericline-Carlsbad is as 3:2:1, while Manebach occurs less frequently, and Baveno occasionally.
35. Phillips, F. Coles, Pericline and acline-A twins in the acid plagioclases: *Rev. de Géol.*, vol. **12,** p. 172, 1931–32. Pericline twinning should be frequent in crystalline schists.
36. Rath, G., *Monstslier: K. Akad. Wiss. Berlin*, **1876.** Cited from Lewis (24). Manebach and pericline twins are described.
37. Riba, J. M., Leslleis de macha dels feldespats de vàries roques de Camarena, Bagur, Ferragut i Eivissa, determinades pels mèthodes universals de Fedorow: *Neues Jahr. f. Min.*, vol. **1,** p. 192, 1925. It is stated that some twin laws occur frequently and some less frequently.
38. Rittmann, A., Die Zonenmethode: *Schw. Min. u. Petr. Mitt.*, vol. **9,** p. 1, 1929.
39. Sabot, R., Les mâcles des feldspaths: *Min. Abst.*, vol. **3,** no. 11, p. 516, 1928. Feldspar twins are classified after research by Fedorov's method.
40. Schlossmacher, K., Einige Beispiele von "selteneren" Feldspatzwillingsgesetzen en Einsprenglingsalbiten deutscher Keratophyre: *Cent. f. Min.*, pp. 193–203, **1920.** Examples are given of Ala and albite twins. Manebach twins are more common than supposed.
41. Schröder, A., Ein Beispiel für das Enfola-Zwillingsgesetz am Orthoklas: *Cent. f. Min. Geol. u. Petr.*, **A,** p. 353, 1932. A crystal twinned on ($\bar{4}03$) is described in detail.
42. Solignac, M., Observations statistiques sur les plagioclases des dolérites du Basutoland occidental: *Rev. de Géol.*, vol. **13,** p. 88, 1932–33. The twins found in the phenocrysts and microlites are listed with their frequency of occurrence.
43. Spencer, E., A contribution to the study of moonstone from Ceylon and other areas and of the stability-relations of the alkali-feldspars: *Min. Mag.*, vol. **22,** no. 130, p. 296, 1930. Feldspars with Baveno twinning were found.
44. Taylor, W. H., Darbyshire, J. A., and Strunz, H., An X-Ray investigation of the feldspars: *Zeit. Krist.*, vol. **87–88,** p. 464, 1934. Twinning is produced during crystallization, small disturbance causing the complex twins.
45. Tsuboi, S., A dispersion method of discriminating rock-constituents and its use in

petrogenic investigation: *Jour. Fac. Sci., Imp. Univ. Tokyo,* vol. **1**, pt. 5, p. 139, 1926. The method and determinative curves are described.

46. Vendl, A. and Takáts, T., Untersuchungen über die Verwitterung des Andesits vom Csódiberge (Ungarn): *Min. u. Petr. Mitt.*, vol. **43–44**, pp. 437–463, 1933. The twin laws and compositions in the groundmass are given.
47. Viola, C., *Zeit. Krist.*, p. 305, **1900.** Cited from Lewis (24).
48. Walker, T. L., Plagioclase in graphic-granite: *Univ. Toronto Studies, Geol. Ser.*, 1932, *Contr. to Canada. Min. Nr.* **32**, pp. 11–13. Albite and pericline twins occur in the plagioclases.
49. Wang, S. W., A study on the orthoclase cyrstals and twins of Chiaocheng, Shansi: *Neues Jahr. f. Min. u. Geol.*, vol. **1**, p. 354, 1934. The twins in a pegmatite are named.
50. Wieseneder, H., Die Plagioklase im Trachydolerit des Pauliberges (Burgenland): *Min. u. Petr. Mitt.*, vol. **43–44**, pp. 199–204, 1933. Twin laws and An content are given.